APPENDIX

Underway CO_2 Measurements aboard the RVIB Palmer and Data Management of the Global VOS Program

Taro Takahashi
Lamont-Doherty Earth Observatory of Columbia University
Palisades, NY

1. INTRODUCTION:

This proposal is a request for the fourth year continuation of the active NOAA grant which is ending August 31, 2008: **NA030AR4320179P27** entitled "Underway CO_2 Measurements aboard the RVIB Palmer and Data Management of the Global VOS Program". In this proposal, the funds supporting the activities of the Lamont-Doherty Observatory (LDEO) and the Bermuda Institute for Ocean Sciences (BIOS, formerly BBSR) (as a subcontract) are requested jointly. Although these groups share a common goal for the elucidation of sea-air CO_2 flux over the oceans, the progresses made by each group are documented separately.

2. SCIENTIFIC OBJECTIVES:

The sea-air net flux of CO_2 is governed by the difference between pCO_2 in surface ocean water and the overlying atmosphere as well as by the gas transfer rate across the sea-air interface. The seawater pCO_2 depends primarily on the processes occurring within the sea (such as seawater temperature, biological productivity and upwelling of deep waters), and the gas transfer rate is regulated mainly by atmospheric processes including turbulence of the interface induced by winds. The primary objective of this proposed investigation is to determine the space-time distribution of the ocean surface pCO_2 and the sea-air pCO_2 difference. Combining the sea-air pCO_2 difference with the CO_2 gas transfer coefficient which is being investigated by other scientific groups, a reliable net sea-air flux of CO_2 over regional to global scales can be estimated using improved sea-air pCO_2 difference data. The work by the LDEO group is primarily focused in the southern high latitude areas surrounding the Antarctic continent, whereas the BIOS group is in the western North Atlantic Ocean. Thus, the results will give us an improved geographical coverage for the sea-air CO_2 transfer flux over the global ocean.

The LDEO group operates a semi-automated surface water pCO_2 system aboard the RVIB Nathaniel Palmer with significant operational assistance from the Raytheon Polar Support group (funded by NSF). RVIB Palmer is an ice-breaking research vessel, one of the few research ships operated in high latitude areas of the Southern Ocean even during winter months. Hence, the LDEO program yields observations critical to our understanding of the role of the high latitude Southern Ocean around Antarctica including the Weddell and Ross Seas in the global carbon cycle (see Fig. 1). The BIOS program is directed to the mid-latitude areas of the western North Atlantic Ocean aboard a container ship Oleander and R/V Weatherbird II and Atlantic Explorer.

Our proposed work is a part of a consortium of investigators who operate their respective pCO_2 systems aboard other research and commercial vessels. The consortium includes the following groups: Richard Feely and his PMEL/NOAA group investigate

mainly the equatorial Pacific aboard the NOAA ships; Rik Wanninkhof and his group at AOML/NOAA are primarily responsible for measurements over the Atlantic Ocean;; Frank Millero and his group at the University of Miami investigates coastal waters and Caribbean Sea. Pooling of the data among the participants will allow us to cover a large part of the global oceans. Under this grant, the Lamont-Doherty Observatory group is responsible for quality-control and management of the data produced by the NOAA-supported groups as well as those from international collaborators from Japan, Iceland, Germany and France. The data are processed into a single uniform format and are made accessible to the participants via the LDEO web site (www.ldeo.columbia.edu/CO2).

3. PROGRESS TO DATE, LDEO Program:

The progress made during a period January, 2001 through April, 2008, is described in this section.

3-A) LDEO Field Program aboard the RVIB Palmer:

The Lamont group is primarily responsible for the acquisition of the surface water pCO_2 data aboard the RVIB Palmer. Our pCO_2 system has been upgraded a year ago with the support from NOAA, and some new modifications are being added in order to make the system more stable and reliable. As the data are obtained, they are processed and added to our global database, which consists presently of about 3.4 million pCO_2 measurements in surface waters plus supplemental information including the SST, salinity, wind speeds, barometric pressure and atmospheric CO_2 concentration.

The locations of our data obtained since the beginning of this project in 2001 are shown in Figure. 1, and the dates, location and number of measurements are listed in Table 1. The total number of surface water pCO_2 data obtained to date is 637,382, of which about 93,481 measurements were added to the database during this project year 2007-08.

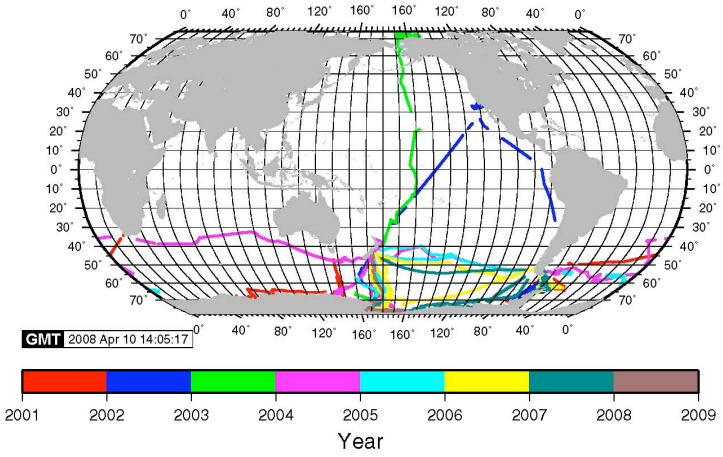

Fig. 1- The locations of surface water pCO_2 measurements made aboard the RVIB Palmer since 2001. The yellow lines indicate the observations made during the current project year 2007-08, about 93,481 pCO_2 measurements were obtained.

Table 1 – List of the RVIB N. B. Palmer expeditions and the number of surface water pCO_2 measurements obtained from January, 2001 through April, 2008.

Cruise No.	Project Name	Dates	No. Obs.	Annual No.
01/1	East Antarctic Margin	30 Jan - 20 Mar 2001	12,300	
01/2	SouthWest Pacific	01-19 Apr 2001	6,541	
01/3	SO-GLOBEC	23 Apr - 06 Jun 2001	20,446	
01/4	SO-GLOBEC	21 Jul - 01 Sep 2001	14,960	
01/5	Antarctic Peninsula	07 Sep - 26 Oct 2001	27,312	
01/6	SO-GLOBEC	09 Nov- 01 Dec 2001	10,317	
01/7	Antarctic Peninsula	05 Dec 01 - 12 Jan 02	22,627	**114,503**
02/1	Antarctic Penninsula	18 Jan - 04 Mar 02	24,542	
02/2	GLOBEC III	09 Apr - 21 May 2002	25,327	
02/4	GLOBEC IV	31 Jul - 09 Sep 2002	29,640	
02/5	Transit along W. South America	23 Sep - 19 Oct 2002	8,317	
02/6	USCG Inspection	30 Oct - 08 Nov 2002	6,732	
02/7	Reconst. of Paleo S. Pac.	10 Nov - 06 Dec 2002	5,702	
02/9	ANSLOPE, Transit fm Lyttleton to McMurdo	11 Dec 2002 - 03 Jan 2003	6,925	**107,185**
03/1	Ross Ice Shelf Survey	5 - 30 Jan 2003	8,062	
03/1A	Ross Sea Research	2-20 Feb 2003	7,227	
03/2	Ross Sea Research	25 Feb - 09 Apr 2003	13,897	
03/4	Transit N.Z to Alaska	23 May - 02 Jul 2003	9,864	
03/4A	Alaska North Slope	06 Jul - 18 Aug 2003	17,136	
03/5	Southern Ocean near 175E	26 Oct - 13 Dec 2003	7,427	
03/5A	Ross Sea Research	18 Dec 2003 - 02 Jan 2004	4,501	**68,114**
04/1	Western Ross Sea	20 Jan - 19 Feb 2004	12,299	
04/2	ANSLOPE III	26 Feb - 11 Apr 2004	17,708	
04/3	Transit New Zealand to Chile	16 Apr - 12 May 2004	9,463	

04/4	Ice Fish	18 May - 19 Jul 2004	22,755	
04/6	Transit, South Africa to New Zealand	27 Jul - 04 Sep 2004	14,277	
04/8	ANSLOPE IV	12 Oct - 06 Dec 2004	21,958	
04/9	Biochemical Research	18 Dec 2004 - 25 Jan 2005	14,443	**112,903**
05/1	ANSLOPE/IVARS	28 Jan - 15 Feb 2005	5,736	
05/1B	N.Z. to Chile Transit	03 - 22 Mar 2005	7,494	
05/2	Antarctic Penninsula	02 - 24 Apr 2005	8,235	
05/5	Coastal Chile	23 Jun - 14 Jul 2005	3,983	
05/6	Maud Rise	20 Jul - 18 Sep 2005	19,066	
05/7	Chile to N.Z. Transit	23 Sep - 21 Oct 2005	9,554	
05/8	Ross Sea Biology	26 Oct - 12 Dec 2005	18,387	**72,455**
06/1	Interaction of Iron, Light, & CO2	17 Dec 05 - 30 Jan 06	16,174	
06/2	Late Cretaceous & Cenozoic Recreations	03 Feb - 23 Mar 2006	7,740	
06/3	Paleo History of Larsen Ice Shelf	12 Apr - 05 May 2006	10,005	
06/6	Plankton Community Struct & Iron Concent.	03 Jul - 18 Aug 2006	17,565	
06/8	Ross Sea Plankton Dynamics	01 Nov - 15 Dec 2006	17,257	**68,741**
07/1	Geological Research	22 Dec 2006 - 29 Jan 2007	14,963	
07/2	Amundsen Sea Research	03 Feb - 25 Mar 2007	20,780	
07/3	Collaborative Research	31 Mar - 05 May 207	12,781	
07/4	Open Period	10 May - 20 Jun 2007	no data	
07/5	Transit to Maintenance Period	21 - 25 Jun 2007	pending	
07/6	Drydock	25 Jun - 28 Jul 2007	no data	
07/7	Transit to Punta Arenas, Chile	28 Jul - 02 Aug 2007	pending	
07/8	Open Period	02 - 27 Aug 2007	no data	
07/9	Sea Ice Balance in the Antarctic	01 Sep - 31 Oct 2007	14,616	
07/10	Palmer Station Resupply	14 Nov - 07 Dec 2007	8,548	
07/11	Transit, Chile - New Zealand	14 - 30 Dec 2007	6,355	**78,043**
08/1	Ross Sea Research	08 - 27 Jan 2008	6,876	
08/2	Ross Sea Research	29 Jan - 20 Feb 2008	8,562	
08/3	Ross Sea Research	Feb - Mar 2008	pending	
08/4	Ross Sea Research	Mar - Apr 2008	pending	**15,438**
GRAND TOTAL SINCE THE BEGINNING OF THE PROJECT				**637,382**

3-B) pCO_2 Data Processing and Management at LDEO for the VOS Program:

The Lamont group is responsible for processing and managing the surface water pCO_2 data acquired by the members of the Volunteer Ocean Survey (VOS) consortium, so that the participants of the program are able to access of the data in an uniform electronic format. For this purpose, we have established an open web site at the following URL: http://www.ldeo.columbia.edu/CO2. The site provides not only the numerical data, but also maps showing the ship's tracks for each data file. The new data will be accessible only to the VOS participants for a period of three years, and will be released to the public after this period.

As a part of the VOS program, we added quality-controlled data to our database from the following field operations; 1) the R/V Laurence M. Gould, which is supported by

NSF as a part of the Long-Term Research in Environmental Biology (LTRE) program in the Drake Passage area, Southern Ocean; 2) the NOAA's Ronald Brown program, mostly in the Atlantic Ocean (R. Wanninkhof); 3) the "Explorer of the Seas" program in and around the Caribbean Sea (R. Wanninkhof); 4) the Kaimimoana program in the equatorial Pacific (R. A. Feely). The sampling locations during the R/V L. M. Gould program are shown in Figure 2. The dates and the number of pCO_2 measurements made during each of these programs are summarized in Table 2. A total of approximately 67,307 pCO_2 measurements that were made aboard the R/V Gould during this funding period have been added to our database. This makes a total of 326,393 pCO_2 measurements for the Gould program from March, 2002 through April, 2008.

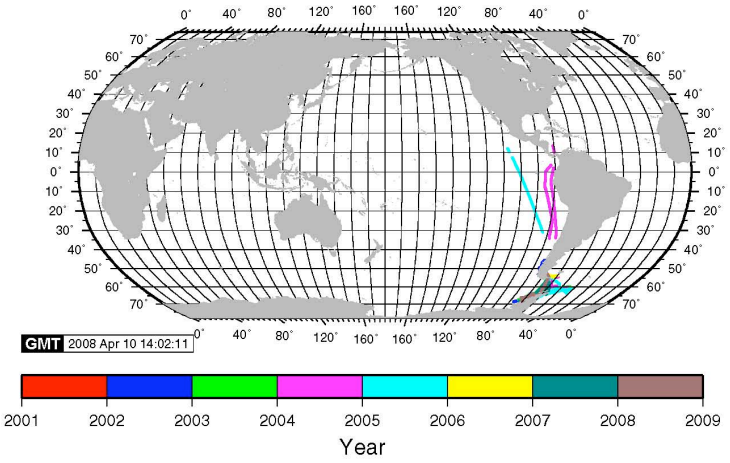

Figure 2 – The locations of the surface water pCO_2 measurements obtained aboard the R/V Gould during this project, March, 2002 through April, 2008. A total of 326,393 pCO_2 measurements were made since the beginning of the project in 2002. During the current funding period 2007-2008, 67,307 pCO_2 measurements were made. The years of the measurements are color coded. These data have been processed and quality-controlled by the VOS project.

Table 2 – List of the R/V Laurence M. Gould expeditions and the number of surface water pCO_2 observations added to the VOS database since the inception of this project in 2002.

Cruise No.	Project Name	Dates	No. Obs.	Year Total
02/1	Antarctic Penninsula	07 - 18 Mar 02	2,731	
02/2	Palmer Shuttle	22 Mar - 02 Apr 02	1,879	
02/3	GLOBEC III	07 Apr - 20 May 2002	8,659	
02/4	Palmer Shuttle	21 Jun - 22 Jul 2002	4,815	
02/5	GLOBEC IV	29 Jul - 19 Sep 2002	6,787	
02/6	Palmer Shuttle	23 Sep - 07 Oct 2002	2,332	
02/8	Open Cape Shirreff	03 Nov - 17 Nov 2002	3,137	
02/9	Scotia Arc GPS Project	23 Nov - 23 Dec 2002	8,209	**38,549**
03/1	LTER	31 Dec 2002 - 08 Feb 2003	13,831	
03/2	GLOBEC	13 Feb - 07 Mar 2003	4,167	
03/2	Palmer Shuttle	12 Mar - 29 Mar 2003	5,721	
03/4	Biological Research	05 Apr - 07 May 2003	9,334	
03/4A	Biological Research	10 May - 05 Jun 2003	4,629	
03/5	Palmer Shuttle	15 Jun - 29 Jun 2003	2,618	

03/5A	Palmer Shuttle	15 Aug - 04 Sep 2003	5,774	
03/6	Palmer Shuttle	23 Sep - 06 Oct 2003	2,495	
03/7	Palmer Shuttle	10 - 22 Oct 2003	3,450	
03/8	Palmer Shuttle	07 - 18 Nov 2003	3,758	
03/9	Antarctic Penn Research	23 Nov - 29 Dec 2003	12,288	**68,065**
04/1	Antarctic Penn Research	01 Jan - 07 Feb 2004	12,556	
04/2	Antarctic Penn Research	12 Feb - 24 Mar 2004	14,222	
04/3	Antarctic Penn Research	28 Mar - 12 Apr 2004	2,100	
04/4	Antarctic Penn Research	16 Apr - 10 May 2004	5,510	
04/5	Antarctic Penn Research	14 - 24 May 2004	3,797	
04/6	Palmer Shuttle	30 May - 09 Jun 2004	2,609	
04/7	Palmer Shuttle	13 - 27 Jun 2004	2,835	
04/8	Transit Chile to Louisiana	06-16 Jul 2004	3,849	
04/11	Palmer Shuttle	25 Sep - 12 Oct 2004	3,165	
04/12	Palmer Shuttle	17 - 30 Oct 2004	2,091	
04/13	Palmer Shuttle	08 - 18 Nov 2004	4,014	
04/14	Palmer Shuttle	24 Nov - 31 Dec 2004	10,916	**67,664**
05/1	LTER Palmer Penn.	31 Dec 2004 - 05 Feb 2005	14,091	
05/2	Palmer Shuttle	11 Feb - 11 Mar 2005	11,411	
05/3	Palmer Shuttle	15 Mar - 29 Mar 2005	2,398	
05/4	Palmer Shuttle	04 - 07 Apr 2005	1,377	
05/5	Palmer Shuttle	21 Apr - 11 May 2005	3,675	
05/6	Palmer Shuttle	19 May - 09 Jun 2005	3,126	
05/7	Palmer Shuttle	14 - 28 Jun 2005	2,837	
05/8	Hazmat Transit	03 - 31 Jul 2005	4,440	
05/9	Hazmat Transit	23 Aug - 03 Sep 2005	3,876	
05/11	Palmer Shuttle	17 - 29 Sep 2005	2,436	
05/12	Palmer Shuttle	23 Oct - 03 Nov 2005	3,032	
05/14	Palmer Shuttle	08 - 21 Nov 2005	3,900	
05/15	Palmer Shuttle	27 Nov - 26 Dec 2005	6,462	
06/1	LTER Antarctic	01 Jan - 08 Feb 2006	10,538	
06/2	Deploy Engler Buoys	14 Feb - 18 Mar 2006	8,137	
06/3	Palmer Shuttle	21 Mar - 04 Apr 2006	3,072	**84,808**
07/1	LTER Antarctica	01 Jan - 11 Feb 2007	12,376	
07/2	Peterman Is. Pickup, Close Stations	16 Feb - 01 Mar 2007	3,766	
07/3	Palmer Station Shuttle	08 - 19 Mar 2007	2,439	
07/4	Palmer Turnover	23 Mar - 06 Apr 2007	2,637	
07/5	Biological Research	11 Apr - 09 May 2007	6,997	
07/6	Logistic Cruise	12 May - 03 Jun 2007	5,290	
07/7	Hazardous Waste Shuttle	07 - 22 Jun 2007	2,414	
07/8 -11	Dry dock maintenance	23 June - Sept 12, 2007	0	
07/12	Palmer Station Opening	13 - 29 Sep 2007	3,200	
07/13	COPA Opening	08 - 20 Oct 2007	2,750	
07/14	Open Period, maintenance	21 Oct - 3 Nov, 2007	0	
07/15	Palmer Shuttle	04 - 16 Nov 2007	3,395	
07/16	Not Used			
07/17	Antarctic Penn. Research	22 Nov - 22 Dec 2007	9,960	**55,224**

08/1	LTER Antarctica	30 Dec 2007 - 09 Feb 2008	12,083	
08/2	COPA Opening	14 Feb - 17 Mar 2008	Pending	
08/3	Palmer Turnover	22 Mar - 04 Apr 2008	Pending	
08/4	Palmer Shuttle	08 - 23 Apr 2008	Pending	**12,083**
GRAND TOTAL SINCE THE BEGINNIN OF PROJECT				**326,393**

The data obtained by the AOML/NOAA and PMEL/NOAA groups are summarized in Table 3. For this funding period of 2007-08, about 171,787 measurements were obtained aboard the Ronald Brown, the "Explorer of Sea", the Kaimimoana and the Columbus Waikato. The total number of surface water pCO_2 measurements made by these NOAA groups since 2001 through April 2008 is about 777,226.

Table 3 - Surface water pCO_2 data received from the AOML/NOAA and PMEL/NOAA groups for quality control and archiving. These data have been quality-controlled and added to the VOS database.

Year	Number of Legs (files)		pCO_2 Obs	Ship Total
Ship:	**Ronald Brown**			
2001	12		41,358	
2002	13		26,341	
2003	10		26,291	
2004	10		23,499	
2005	10		26,714	
2006	11		32,537	
2007	0	0		
				176,740
Ship:	**Explorer of the Seas**			
2002	30		39,262	
2003	39		76,322	
2004	50		82,043	
2005	44		67,231	
2006	39		57,576	
2007	35	53,268		
				375,702
Ship:	**Kaimimoana**			
2001	2		5,641	
2002	5		15,017	
2003	5		18,597	
2004	4		13,742	
2005	0		0	
2006	0	0		
2007	2			

		34,009		
				87,006
Ship:	**Columbus Waikato**			
2004	6		42,907	
2005	16		84,134	
2006	1		8,737	
2007	0	0		
				137,778
	Grand Total			**777,226**

3-C) LDEO Data Analysis and Synthesis:

The pCO_2 data obtained and archived by the present grant have been used extensively in the following research papers and government reports, that have been prepared during this grant period, 2007-08.

Corbiere, A., Metzl, N., Reverdin, G., Brunet, C. and Takahashi, T. (2007). Interannual variability of the carbon dioxide and air-sea CO2 fluxes in the North Atlantic subpolar gyre:1993-2003 (SURATLATIC Program). Tellus, 59B, 168-178.

Chavez, F. and Takahashi, T. (2007). Coastal oceans, Chapter 15, in "The First State of the Carbon Cycle Report (SOCCR): North American Carbon Budget and Implications for the Global Carbon Cycle". A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research [King, A.W. L. Dilling. G.P. Zimmerman, D.M. Fairman, R.A. Houghton, G.H. Marland, A.Z. Rose, and T.J. Wilbanks (eds.)] National Ocean and Atmospheric Administration, Climate Program Office, Silver Spring, MD, USA, pp. 83-92.

Takahashi, T., Sutherland, S. C. and Kozyr, A. (2008). Global Ocean Surface Water Partial Pressure of CO_2 Database: Measurements Performed during 1968-2006 (Version 1.0). ORNL/CDIAC-152, NDP-088. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U. S. Department of Energy, Oak Ridge, TN 37831, pp.20.

Takahashi, T. S.C. Sutherland, R. Wanninkhof, C. Sweeney, R. A. Feely, D. W. Chipman, B. Hales, G. Friederich, F. Chavez, A. Watson, D. C. E. Bakker, U. Schuster, N. Metzl, H. Yoshikawa-Inoue, M. Ishii, T. Midorikawa, Y. Nojiri, C. Sabine, J. Olafsson, Th. S. Arnarson, B. Tilbrook, T. Johannessen, A. Olsen, Richard Bellerby, A. Körtzinger, T. Steinhoff, M. Hoppema, H. J. W. de Baar, C. S. Wong, Bruno Delille and N. R. Bates (in press). Climatological mean and decadal changes in surface ocean pCO_2, and net sea-air CO_2 flux over the global oceans. Deep-Sea Res. II.

Scott C. Doney, Ivan Lima, J. Keith Moore, Keith Lindsay, M. Behrenfeld, Natalie Mahowald, Matthew Maltrud, David M. Glover, Dennis McGillicuddy, and Taro Takahashi (in press). Skill metrics for confronting global upper ocean ecosystem-biogeochemistry models against field and remote sensing data. Jour. Marine Systems, Special Issue "*Skill Assessment for Coupled Biological/Physical Models of Marine Systems*"

Sabine, C. L., Feely, R. A., Wanninkhof, R. and Takahashi, T. (in review). The global ocean carbon cycle. Bulletin of the American Meteorological Society

4. PROGRESS TO DATE FOR THE BIOS PROGRAM:

4-A) Container Ship Oleander- BIOS lead

4-A-1) Description:

The MV *Oleander* crosses weekly between New Jersey and Hamilton, Bermuda. Given the ~100 crossings a year, this gives excellent temporal and spatial coverage of the North Atlantic subtropical gyre, Gulf Stream, middle Atlantic Bight and coastal zone. The MV *Oleander* transits the region of Subtropical Mode Water (STMW) formation during the winter southeast of the Gulf Stream, and the highly productive coastal zone of the Eastern Seaboard.

4-A-2) Data Return:

The pCO_2 system was installed on the MV *Oleander* in February 2006. Over the year, the total data collected was ~108,000, with a ~68% data recovery. The remaining 32% had some caveats associated with flow rates through the Licor. The MV *Oleander* system uses a LiCOR 7000 NDIR detector, and there are a few minor unresolved issues of comparability to systems with a LiCOR 6262 NDIR detector. Maintenance of the pCO_2 system has become relatively routine with weekly visits to the ship during the ship's turnaround in Hamilton, Bermuda. Our group has developed a good rapport with the ship officers, engineers and crew, and their good will has contributed greatly to the success of the system installation on the ship.

The seawater and atmospheric pCO_2 data from 2006 and 2007 (up to May) have been submitted to LDEO. We are in the process of preparing the metadata information and data QC/QA for submission of data to CDIAC in yearly reports (i.e., 2006, 2007). The seawater and atmospheric pCO_2 data will also be served at the following site (http://www.bios.edu/Labs/co2lab/vos.html).

4-A-3) Causes for non-return:

On the MV *Oleander*, the primary causes for non-return have been associated with ship-related issues (seawater pump system turned off; delays getting on to the ship); failure of the waste reservoir and delays related to component replacement. Over the last year there have been occasions when the seawater system were not turned on during the weekly turnaround of the ship. There have also been several occasions when our group has not been able to access the ship in port due to offload/onload pressures when the ship is undertaking very quick turnarounds due to weather delays. On a couple of occasions, the pump that drains seawater from the waste reservoir has failed and we have had delays in replacing the pump. The equilibrator is located in the Engine Room near the seawater system and TSG. It is located ~5' below the water line, requiring the equilibrator waste seawater to free drain into a waste reservoir, which in turn is drained by a pump back into the seawater line downstream of the tap off to the pCO_2 system. In 2007, the pump has failed twice with shutdown of the system after overflow into the ship's bilges. Recently, we have added a second, stronger pump to ensure that the waste water is pumped overboard.

The primary filter on the seawater intake line has also needed to be cleaned each week; otherwise rust and debris from the *Oleander*'s internal plumbing clogs the line and slows the flow rate into the equilibrator. We have also had problems with the Superlogic Module boards; these modules have had to be replaced. The condenser tubes have clogged with salt crystals causing a shutdown of the system. The condenser tubes have been replaced. The average temperature of the engine room has been ~47°C with the CPU failing in 2006 due to temperatures over 60°C. We have modified the dry box, adding new fans, and replaced the CPU with one that has a higher temperature threshold (80*C) with no problems since. The replacement of the CPU caused a problem with the GPS comport that is currently being addressed. The engine room air is quite dirty requiring cleaning of all filters each week.

4-B) R/V Atlantic Explorer - BIOS lead

4-B-1) Description:

The R/V *Atlantic Explorer* operates in the North Atlantic Ocean (primarily zone NA6), servicing four oceanographic time-series (e.g., Bermuda Atlantic Time-series Study, Hydrostation S, Bermuda Testbed Mooring, Ocean Flux Program) and other research projects. This data stream provides groundtruthing pCO_2 datasets for the subtropical gyre of the North Atlantic Ocean. In 2007, the *Atlantic Explorer* is scheduled for 173 days. In 2008, the *Atlantic Explorer* is scheduled for approximately 179 days.

4-B-2) Data Return:

The pCO_2 system was installed on the RV *Atlantic Explorer* in April 2006. Over the last 16 months, the total data collected was ~92,000, with a ~83% data recovery. The remaining 17%% were flagged due to problems associated with the Valco multi-position valve and distribution of standards through the system, and delays in replacing the standards. Maintenance of the pCO_2 system has become relatively routine during the ship's turnaround at the BIOS dock. The seawater and atmospheric pCO_2 data from 2006 and 2007 (up to May) have been submitted to LDEO. We are in the process of preparing the metadata information and data QC/QA for submission of data to CDIAC in yearly reports (i.e., 2006, 2007). The seawater and atmospheric pCO_2 data will also be served at the following site (http://www.bios.edu/Labs/co2lab/vos.html).

4-B-3) Causes for non-return:

In 2007, the major problem with the *Atlantic Explorer* system has been intermittent problems with the Valco multiposition valve. The valve has been replaced. We have had problems with the Ivisco valve that controls the flushing of the lines with freshwater. This valve has failed twice due to salt crystal buildup. We have also had problems with clogging of the flow meter impeller. We have also had problems with the Superlogic Module boards due to faulty power feed; these modules have had to be replaced. The acrodisk have also been clogged and in need of regular cleaning. We have also had a few problems with the GPS system, with a faulty 232 to 485 converter, and faulty comport.

4-C) Mooring pCO_2 Effort:

The long-term goal of this program is to populate the network of OCEAN Sustained Interdisciplinary Time-series Environment observation System (OceanSITES; http://www.oceansites.org/) so that CO_2 fluxes will become a standard part of the global flux mooring network.

4-C-1) Bermuda Testbed Mooring (64.2°W, 31.7°N)

A moored pCO_2 system was first deployed on the Bermuda Testbed Mooring (BTM) on October 22, 2005. The system was fully operational for the entire FY06. The system was successfully recovered and redeployed in July 2006. The system is currently operational. The percent data return is as follows, FY06: 100% and Lifetime: 100%.

4-D) Data management and dissemination:

The efforts of the NOAA VOS pCO_2 group have met the important monitoring principle of uniform instrumentation with a quantifiable accuracy. All systems are calibrated with standards that are traceable to the WMO scale. An important part of the VOS effort is to disseminate quality controlled data to the community at large in an expedient fashion. The seawater and atmospheric pCO_2 data will also be served at the following site (http://www.bios.edu/Labs/co2lab/vos.html). After QC and QA, data will be transferred to LDEO.

4-F) Research highlights:

The VOS CO_2 data is providing valuable information on CO_2 variability in surface seawater over a wide range of time- and spatial scales that have not been fully examined. In 2006 And 2007, both ships collected high frequency data in the region of the subtropical gyre of the North Atlantic Ocean, Gulf Stream, Middle Atlantic Bight and coastal ocean of the eastern seaboard.

Comparisons of underway seawater pCO_2 data collected from BIOS's ship, R/V *Atlantic Explorer* with the BTM pCO_2 sensor have been initiated. Over 15,000 seawater pCO_2 datapoints were collected from the Atlantic Explorer within 80 km of the BTM in 2006. Seawater pCO_2 data collected from the R/V *Atlantic Explorer* underway system within 10 km of the BTM (also within 3 minutes of each BTM datapoint) had an average difference of less than 0.5 µatm.

4-G) Community Service, Conferences attended, and Outreach:

Nicholas R. Bates: IOCCP SSG meeting (Paris, April 2007); SOLAS-IMBER Carbon meeting (Paris, April 2007); Implementation planning meeting (Miami, December 2005); *Atlantic Meridional Transect* (AMT) meeting, Royal Society, July 2006. *CarboOCEAN* meeting, UEA, Sept. 2006

Committees He has contributed to the Intergovernmental Panel on Climate Change (IPCC) 4th Assessment, and the SOLAS-IMBER joint carbon implementation plan. Bates is a member of the IOC-SCOR International Ocean Carbon Coordination Project (IOCCP) scientific steering group, and SOLAS-IMBER Carbon working group. Bates is a member of the US Carbon Cycle Scientific Steering Group (CCSSG), an advisory for the Carbon Cycle Interagency Working Group (CCIWG).

4-H) Publications:

Bates, N.R., Purinton, B., and Jeffries, M., 2006. Air-sea carbon dioxide exchange and fate of carbon in Eighteen Degree Water (EDW) of the North Atlantic Ocean: Initial results from the 2006 CLImate MOde water Dynamics Experiment (CLIMODE). *AGU meeting*. San Francisco, December 2006.

Bates, N.R., 2007. Interannual variability of the oceanic CO_2 sink in the subtropical gyre of the North Atlantic Ocean over the last two decades. *Journal of Geophysical Research (Oceans),* doi:10.1029/2006JC003759.

Marshall, J.D., Andersson, A.J., Bates, N.R., Dewar, W., Doney, S.C., Edson , J., Ferrari, R., Fratantoni, D., Gregg , M., Joyce, T., Kelly, K., Lozier, S., Lumpkin , R., Samelson, R., Skyllingstad, E., Straneo, F., Talley, L., Toole, J., and Weller, R., 2008. CLIMODE: a mode water dynamics experiment in support of CLIVAR. *Bulletin of the American Meteorological Society* (in preparation).

Neely, K., Bates, N.R., Johnson, R.J., and McGillicuddy, D.J., 2008. The influence of mesoscale eddies on inorganic carbon cycling and air-sea CO_2 gas exchange in the North Atlantic Ocean. *ASLO/AGU Ocean Sciences meeting*, Orlando, March 2008.

Schuster, U., Watson, A.J., Bates, N.R., Corbiere, A., Gonzalez-Davila, M., Metzl, N., Pierrot, D., Santana-Casiano, M., 2008. Decadal changes in the CO_2 sink of the North Atlantic Ocean. *Deep-Sea Research II* (special volume on Paris CO_2 meeting, April 2007) (accepted with revisions)

Takahashi, T., Sutherland, S.C., Wanninkhof, R., Sweeney, C., Feely, R.A., Chipman, D.W., Hales, B., Friederich, G.E., Chavez, F.P., Watson, A.J., Bakker, D.C.E., Schuster, U., Metzl, N., Yoshikawa-Inoue, H., Olafsson, J., Arnarson, T.S., Tilbrook, B., Johannessen, T., Olsen, A., Bellerby, R.J., de Baar, H.J.W., Nojiri, Y., Wong, C.S., Delille, B., Bates, N.R., and de Baar, H.W., 2008. Climatological mean and decadal change in surface ocean pCO_2, and net sea-air CO_2 flux over the global oceans. *Deep-Sea Research II* (in press)